Rotor Design Options for Whirl Flutter

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Coupled wing/rotor whirl-mode aeroelastic instability is the major barrier to increasing tilt-rotor speeds. This research investigated the unusually simple approach of adjusting the chordwise positions of the rotor blade aerodynamic center (a.c.) and center of gravity (c.g.) to improve the stability boundary of the full aircraft. The XV-15 tilt-rotor research aircraft was modeled with the CAMRAD II rotorcraft analysis program; the model was then modified to simulate a thinner wing, which had lower drag but also a lower stability boundary than the baseline wing. Numerous rotor modifications were studied to determine their effects on whirl flutter for the XV-15 with the new wing.

Small stepwise, rearward offsets of the a.c. over 20% of the blade radius created large increases in the stability boundary, in some cases by over 100 knots. The effect grew progressively stronger as the offsets were shifted outboard. Forward offsets of the c.g. had similar but less dramatic effects. An example of a stepped a.c. offset is shown in figure 1, with the unmodified blade for reference. The a.c. offsets were modeled by shifting the entire airfoil section with respect to the elastic axis (EA), as shown in figure 1.

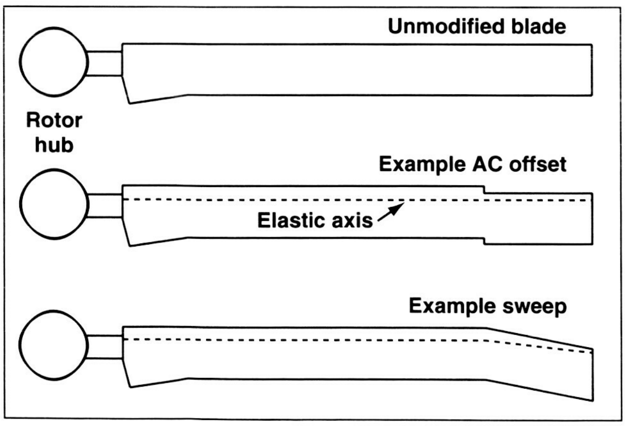

Fig. 1. XV-15 rotor blade planforms: unmodified, stepped offset, and swept (45 degree twist and 1 degree baseline sweep not shown).

The research was extended to include swept blades, which give benefits similar to those of the stepped offsets, but for a much more practical blade configuration. Figure 1 shows an example swept blade with 10-degree a.c. sweep and 5-degree c.g. and a.c. sweep. Although unorthodox, the design is feasible. Control-system (pitch) stiffness was also increased for a further improvement in stability.

Figure 2 summarizes the combined benefits of the example swept blade with doubled control stiffness. Damping of the three unstable whirl modes is plotted against airspeed; the wing/rotor structure is aeroelastically unstable below zero damping. The rotor modifications completely eliminated the instabilities.

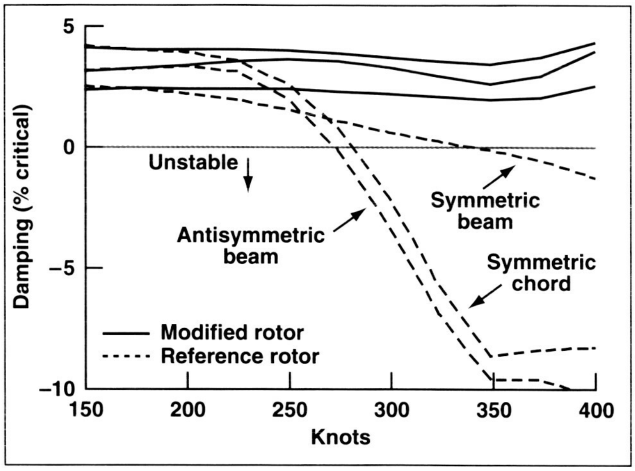

Fig. 2. Whirl-mode damping versus airspeed for the original rotor blade and control system and for the example swept blade with double control-system stiffness. (Modes that were always stable are not shown.)

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